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## *THE TRAINING AND WORK OF A GEOLOGIST.**

GEOLOGY is a dynamic science, subject to the laws of energy. Geology treats of a world alive, instead of, as commonly supposed, a world finished and dead. The atmosphere, or sphere of air, is ever unquiet; the hydrosphere, or sphere of water, is less active, but still very mobile; the lithosphere, or sphere of rock, has everywhere continuous although slow motions. The motions of the atmosphere, the hydrosphere, and the lithosphere alike include body motions by which the positions of large masses of material are changed, and interior motions, through which the mineral particles are constantly rearranged with reference one to another, and indeed are constantly remade. Furthermore, the molecules and even the atoms which compose the atmosphere, hydrosphere and lithosphere have motions of marvelous intricacy and speed. These motions of the atmosphere, the hydrosphere and the lithosphere, are all superimposed upon the astronomical motions—the wobbling revolution of the earth about its axis, the revolution of the earth-moon couple about their common center of gravity, the movement of this couple about the sun at the rate of 68,000 miles per hour, the

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movement of the solar system among other systems. If it were possible for one to fix in space coordinates by which to measure these various motions, the movement of an air particle, of a water drop, of a mineral grain, would be seen to be extraordinarily complex.

It is clear that there is every reason to believe that no atom or molecule in the world ever occupies the same absolute position in space at any two successive moments. Indeed, it must have been an extraordinary accident, if it ever has occurred, that a single particle has occupied in all the history of the universe exactly the same position that it has occupied at any previous time. No such thing as rest for any particle of matter anywhere in the earth or in the universe is known; but, upon the contrary, everywhere all particles are moving in various ways with amazing speed.

No science is independent of other sciences, but geology is peculiar in that it is based upon so many other sciences. Astronomy is built upon mathematics and physics. Chemistry and physics to a considerable degree are built upon each other. Physics also requires mathematics. Biology demands a limited knowledge of physics and chemistry. However, it cannot be said that a knowledge of the basal principles of more than one, or at the most two, other sciences is an absolute prerequisite for a successful pursuit of astronomy, chemistry, physics or biology. This is not true of geology. In order to go far in general geology one must have a fair knowledge of physics, chemistry, mineralogy and biology. These may be called the basal sciences of geology. In certain lines of geology the additional sciences, mathematics, astronomy and metallurgy, are very desirable.

Geology treats of the world. In order to have more than a superficial knowledge of geology, it is necessary to know about the elements which compose the world; how force acts upon these elements; what aggregates are formed by the elements and forces, and how life has modified the construction of the world. Chemistry teaches of matter; how it is made up, both in life and in death. Without an understanding of its principles we cannot have an insight into the constitution of the earth or of any part of it. Physics teaches of the manner in which the many forms of that strange something we call force acts upon matter. Without a knowledge of its principles we can never understand the transformation through which the world has gone. The elements which compose the earth under the laws of physics and chemistry aggregate into those almost lifelike bodies which we call minerals. The minerals are commingled in various ways in the rocks. Without a knowledge of mineralogy no one can have even a superficial understanding of the constitution of rock masses. Biology teaches of the substances alive which clothe the outer part of the earth. Life is one of the most fundamental of the factors controlling the geological transformations in the surficial belt of weathering; it has acted as the greatest precipitating agent in the sea. Life, has had therefore, a profound and far-reaching effect in determining the nature of the sedimentary formations.

The sciences of chemistry, physics and biology have been built up by using minute parts of the materials of the earth. If geology, or a science of the earth, is to be constructed, it must apply to the earth as a whole the principles which have so enlightened us as to the nature and relations of the fractions of the earth which we observe and handle in our laboratories of physics and chemistry and biology.

It thus appears that geology is a composite science; and it might in a certain sense be called an applied science. Indeed

I have often defined geology as the application of the principles of astronomy and physics and chemistry and mineralogy and biology to the earth.

Certainly the earth is the single enormous complex aggregate of matter directly within the reach of man. This highly composite earth is the joint result of the work of astronomical, physical, chemical and biological forces; working on an incomparably vaster scale than can ever be imitated in our laboratories. A study of these mighty results has already advanced at many points astronomy, physics, chemistry and biology, and future studies made with direct reference to the causes which have produced the earth are sure to lead to even greater advances in these studies.

If geology is to become a genetic science, or, more simply, is to become a science under the laws of energy, geology in large measure must become a quantitative science. In the past it has been too frequently true that because a single force or agent working in a certain direction is a real cause of a phenomenon, the conclusion is drawn that it is a sufficient cause. Only occasionally has the question been asked, 'Is this cause only a real cause, but is it an adequate cause?' Very often differences of opinion have arisen between geologists, one holding that this cause is the one which explains the phenomenon; another holding that that is the explanation, and each insisting that the other is wrong. In such cases very rarely is the question asked whether the explanations offered are *contradictory* or *complementary*. In many cases the explanation is not to be found in one cause, but in several or many, and thus frequently the conclusions which have been interpreted to be contradictory are really supplementary. To illustrate: But few writers have assigned more than a single cause for crustal shortening. One has held that secular cooling is *the* cause; another has given a different one, and has held that secular cooling is of little consequence. But it is certain that secular cooling, vulcanism, change of oblateness of the earth, change of pressure within the earth, changes of form of the material of the earth, and various other causes, are not exclusive of one another, but are all supplementary. The ability to perceive the supplementary nature of various explanations offered for a phenomenon is one of the most marked, perhaps the most marked, characteristics of the superior man. The new geology must not only ascertain all of the real causes for crustal shortening, and other phenomena, but in order satisfactorily to solve the problems it must determine the quantitative importance of each. Geology within the next few years is certain to largely pass to a quantitative basis.

If I have correctly stated the relations of geology to the other sciences, it follows as a corollary that those only can greatly advance the principles of geology who have a working knowledge of two or more of the sciences upon which it is based.

By a working knowledge of a science I mean such a knowledge of its principles as makes them living truths. One must not only be able to comprehend the principles, but he must see them in relation to one another; must be able to apply them. It is not sufficient for a carpenter to be able to explain how the hammer and saw and plane and chisel work; he must be able to use them. He must be able to hit the nail on the head; to cut straight; to plane smooth; to chisel true; and do all upon the same piece of timber so as to adapt it to a definite purpose in a building. Just so the geologist must be able to apply as tools the various principles of physics and chemistry and biology and mineralogy to the piece of geology upon which he is engaged; and thus shape his piece to its place in the great structure of geological

science. This is what is meant by a working knowledge of the sciences basal to geology.

It is not supposed that any one man has a comprehensive knowledge of all the basal sciences, or even a working knowledge of their principles; but such knowledge he must have of two or more of them if he hopes to advance the principles of geology. He will be able to handle those branches of his subject with which he deals in proportion as he has a working knowledge of the basal sciences upon which his special branch is based, and will probably correlate this branch with the other branches of the great subject of geology in proportion as his working knowledge of the basal sciences is extensive.

For instance, to advance geological paleontology one must have a working knowledge of the principles of biology and of stratigraphy. To advance any of the lines of physical geology, one must have a working knowledge of the principles of physics, and especially of elementary mechanics. To advance physiography one must have a working knowledge of physics and chemistry. To advance knowledge of the early history of the earth, one must have not only a working knowledge of physics and chemistry, but of astronomy. To advance petrology, one must have a working knowledge of physics, chemistry and mineralogy. To advance the theory of ore deposition or metamorphism, one must know not only the principles of physical geology, with all that implies, but he must have a working knowledge of chemistry, physics, mineralogy and petrology. It is unnecessary to add that a geologist must be able to read some of the modern languages, and be able to express himself clearly and logically in one language.

Considering the breadth and thoroughness of the necessary preliminary training for the successful pursuit of geology, one might anticipate that geology would suffer but little from pseudo-scientists. But this anticipation is based upon the idea that no one attempts geological work, and especially to write geological papers, until he is prepared to do so. All sciences have their cranks. Many a little town has its philosopher who believes that all of the principles of astronomy, of physics, of chemistry, which have been discovered by the great men of the past are absolutely erroneous, and who makes a new start upon the construction of the world, building out of his brain strange vagaries which have no relation to the facts of the universe. While there are temptations to pseudo-scientific work in all sciences, the temptation is nowhere so great as in geology. The planets, sun and stars are far off; the elements are elusive; to do anything with force one must have at least seen the inside of a physical laboratory; the manner of the transformations of living forms is not obvious, or even apparently so, and therefore few write about the constitution of plants and animals who have not closely studied them. But one is born upon the earth; he lives upon the earth; he sees the surrounding hills and valleys. The dullest sees something of the transformations going on. Many naturally become interested in the phenomena of the earth, and without preparation think that they are able to make important contributions to the subject of geology. Thus not only in every city, but in many villages, is a geologist of local repute who has ready explanations for the order of the world.

Geology starts as an easy observational study, and gradually becomes more and more complex until it taxes the master mind to the utmost. This easy start leads to the multitude of local geologists, but geology suffers comparatively little from them. The real injury which the science receives is from some of those who call

themselves professional geologists, are teachers of geology in academies and colleges, or are even members of the staff of state or government surveys. These men have gone further than the local geologist; but perhaps they have been led into the subject for somewhat the same reason, by its easy start as an observational science. A man may begin his career as a geologist by making a few observations here and there and giving a guess as to their meaning. With this beginning he becomes more and more interested, until finally he decides to make geology his profession.

In some cases following this decision the necessity is seen for obtaining a working knowledge of the basal sciences. But too often men who have entered upon geological work have received no adequate training in chemistry, in physics, in biology; and therefore at the outset wholly lack the tools to successfully interpret the phenomena which they observe. But such inadequately trained men feel that a satisfactory explanation of any phenomenon must involve a statement of the underlying chemical or physical or biological principles. In such cases it is safe to say that the explanations given are extremely partial, including only a modicum of truth, and more often than not are absolutely fallacious. Indeed, no other result can be expected from one who lacks a working knowledge of the principles of physics, chemistry and biology. Occasionally there is a clear-sighted, capable man, lacking in adequate training, who does important geological work simply because he knows his limitations, and there stops. But this is very exceptional indeed; and the physical explanations offered by many for various geological phenomena are no less than grotesque.

It has been made plain that a working knowledge of the sciences basal to geology is necessary in order to advance its principles. But I go even further, and hold that such basal knowledge is absolutely necessary in order to do even the best *descriptive* work. Suppose a man to be standing before some complex geological phenomenon. The whole intricate interlocking story is engraved upon the retina of his eye with more than photographic accuracy. The image on the retina is absolutely the same in the eye of this experienced geologist and that of a child. Yet if the child be asked to state what he sees, his statements will be of the most general kind and may be largely erroneous. The experienced geologist with a knowledge of the principles of physics and chemistry and biology interprets the phenomena imaged in terms of these subjects. The engraving on his retina is the same as that of the child, but his brain perceives the special parts of the picture of interest to him in their true proportions. He understands what is important, what is unimportant; he must select and record the things which are important. If he attempted to record all that is imaged in his eye, a notebook would be filled with the phenomena to be described at a single exposure; and yet half the story would not be told. Good descriptive work is discriminative. Good descriptive work picks out certain of the facts as of great value; others of subordinate value; and others of no value for the purposes under consideration. How then can this discrimination be made? How can the facts be selected which are of service? Only by an insight into the causes which may have produced the phenomena. Without this insight to some extent at least a description is absolutely valueless. So far as the geologist has such insight, his description is valuable.

It is frequently urged in opposition to the above that, 'If a person has theories in reference to the phenomena which he observes his descriptions will be erroneous;

he will be biased by his theories.' Unfortunately in many cases this is so; but just so far as it is true, the man fails of the qualities which make a successful geologist. One's theories undoubtedly control in large measure the selection of the phenomena which are to be noted, and the wisdom of the selection is a certain criterion of the grade of the geologist. But whatever the facts selected for record, the statement of them should be absolutely unbiased by the theories. Invariably, good practice requires that the statement of facts and the explanation of these facts shall be sharply separated. Doubtless each geologist who is listening has at different times had different ideas about the same locality, or while away from a locality a new idea has come as to the meaning of the phenomena there observed. Upon returning to the old locality with the new idea, additional observations of value have been made, but all the statements of facts at the previous visits should be found to be absolutely true. In so far as they are untrue, the geologist fails of accuracy, the first fundamental of observation. If the previous observations are found to be largely erroneous, the man who made them has small chance to become a good geologist. The difference between *bad* observation and *good* observation is that the former is *erroneous;* the latter is *incomplete.* Unfortunately in many cases not only are the observations recorded by many men absolutely false, but they are so intertwined with the theories of the author that one is unable to discriminate between what is intended to be fact and what is advanced as opinion. It is needless to say that the case of such a man is hopeless; that there is no possibility that he shall ever become a geologist. I conclude, therefore, that in order to have a standing in the future, even as a descriptive geologist, one must interpret the phenomena which he observes in the terms of the principles of astronomy, physics, chemistry, mineralogy, and biology.

If my statement thus far be true, the outline of the training of a man hoping to become a professional geologist is clear. Such a man should be sent to thorough and long courses in each of the subjects of astronomy, physics, chemistry, mineralogy and biology. This means that a large part of the training of a geologist is the study of the sciences upon which geology is founded. If a man who hopes to be a geologist is wholly lacking in a knowledge of any of the basal sciences, this defect he can probably never make good. Even if he so desires, the time cannot be found. Moreover, chemistry, physics, mineralogy and biology are laboratory sciences and can be satisfactorily handled only in the laboratory. If the fundamental work in the basal subjects has been done in the college or university, one may keep abreast of their progress during later years; but in order to do this, the basal principles must have become living truths to him while a student. If a personal illustration be allowable, during the past five years, in order to handle the problems of geology before me, I have spent more time in trying to remedy my defective knowledge of physics and chemistry and in comprehending advances in these sciences since I was a college student than I have spent upon current papers in geology; and with, I believe, much more profit to my work. If one has a working knowledge of the basal sciences and lacks training in some branch of geology, this defect he may remedy; for he has the foundation upon which to build. But if he lacks knowledge of the primary principles of the basal sciences he is likely to be a cripple for life, although this is not invariably the case. There are conspicuous instances where lack of early training in the basal sciences has been largely remedied by unusual ability and industry, but this has been most diffi-

cult. We should see to it that the young men trained in our colleges and universities, upon whom we place the degree of Doctor in Geology, are not crippled by the necessity of making good in later life defective basal training. Any university which gives a man the degree of Doctor in Geology with a defective knowledge of the basal sciences is wronging the man upon whom the degree is conferred; for this man has a right to expect that his courses shall have been so shaped as to have given him the tools to handle the problems which will arise in his chosen profession.

It is not necessary that all of the basal work shall be done before a man begins his life work, but at least a large part of this work should have been done before a man is given the certificate that he can do the work of a professional geologist. But in any case studies in the basal sciences should not cease when the professional degree is granted. Continued studies not only in the basal subjects but in cognate branches and even those far removed from science should continue through life. The geologist finds that however broad and deep his studies are in basal and cognate subjects, he is continually limited by lack of adequate knowledge of them.

In recent years it has been a mooted question in colleges and universities as to when specialization should begin, rather implying that when specialization begins broadening studies should cease. And, indeed, it is upon this hypothesis that most of the discussion upon this subject has been carried on. Some have held that specialization should not begin until late in the college course, or even rather late in a postgraduate course. Others have held that one should early direct his studies to special subjects which he expects to pursue, and give comparatively little time to other subjects. The argument for this latter course is that competition is now keen; and if a man keeps in the race he must begin to specialize early. It appears to me that both of these answers are inadequate. My answer to the question is that specialization should begin early, but that broadening studies should *not* be discontinued. This rule should obtain not only through the undergraduate course, but in the postgraduate work and during professional life. The specialized work will be better done because of the broad grasp given by the other subjects. The broadening studies will be better interpreted because of the deep insight and knowledge of a certain narrow field. Thus each will help the other. No man may hope for the highest success who does not continue special studies and broadening studies to the end of his career.

But is it held that a geologist lacking an adequate working knowledge of basal studies cannot perform useful service? No, the domain of geology is so great, the portion of earth not geologically mapped and the structure worked out is so vast, the ore and other valuable deposits which have received no study are so numerous, that there is an immense field for the application of well-established principles. In geology, as in engineering and other applied sciences, there is an opportunity for many honest, faithful men to perform useful service to the world even if their early training and capacity are not all that could be desired. But even the application of old principles to new areas will be well done in proportion as the geologist has training in the basal sciences; and to the man who combines with such training talent must necessarily be left the advancement of the philosophy of geology. The philosophy of geology, the inner meaning of phenomena, was the paramount consideration to Hutton and Lyell and Darwin. To them facts were useful mainly that they might see common factors, the great principles which underlie them,

or, in other words, generalization. To correctly generalize in geology involves the capacity to hold a vast number of facts in the mind at the same time; to see them in their length and breadth and thickness; to see them at the same time as large masses and as composed of parts, even to the constituent mineral particles and the elements; to see the principles of physics and chemistry and mineralogy and biology interlacing through them. Only by holding a multitude of facts and principles in one's mind at the same time can they be reduced to order under general laws.

Failure thus to hold in one's mind a large number of facts and principles leads to lack of consistency. Often in a single book or a single chapter, on the same page, or even in the same paragraph or sentence, are contained ideas which are exclusive of one another. They are not seen by the writer to be exclusive of one another because he is so lacking in a command of the principles of the basal sciences that he is not aware of the antagonism. Major Powell once said to me, 'The stage of the development of the human mind is measured by its capacity to eliminate the incongruous.' If this hard criterion were rigidly applied, it would follow that many of our professions have not passed the youthful stage. The man who can insert in the same treatise, chapter or page incongruous ideas saves an immense amount of cerebral tissue for himself. Such a man can write on through chapters and books, and not find it necessary to go back, adjust and interrelate the various parts. There is no action and reaction between the multitude of ideas. The writer has the easy task of holding in his mind at any one time but a few data. He is in delightful and happy unconsciousness of the fact that many of his statements destroy one another. But the man who sees the phenomena and principles of geology in all their complex relations, and tries to express the parts of them he is considering in proportion to one another, and to place his fragment of the science of geology in proper relations to other departments of geology and other natural sciences, has a task before him requiring great mental effort. He must see and understand in three dimensions. At every point he must see the lines of cause and effect radiate and converge upon the phenomena he is considering from many other phenomena and principles. Of course all fail to do this completely in reference to any complex problem. But in so far as success would be attained, the effort must be made. In proportion as one can hold many facts and principles and see their interrelations, he will be able to advance the philosophy of geology. This is the work which burns the brain.

And his results he must express in language, the chief means of communicating ideas and relations. Yet language is linear. By figures, models, maps and illustrations, wisely used, one may to an important degree supply the defects of linear language. Yet language and illustration, even where used to the best advantage, but poorly convey one's ideas. Most conscientious writers require as much or more time to put a complex subject into words and illustrations ready for publication as they do in working out the results.

But upon the other side, and in favor of expression in language, it should be remembered that there is action and reaction between one's ideas and the attempt to express them in words and illustrations. The necessity for expression in language is often a wonderful clarifier of ideas. The ideas are improved by the attempt at expression, and the expression is continually improved as the ideas are enlarged.

That the difficulty as to expression does not apply to geology alone is well illustrated by the vast amount of labor Charles Darwin

spent in putting into the linear form of language the most revolutionary work of the time, 'The Origin of Species.' It seemed as if the intricately interrelated facts of life were of so complex a nature that language could not handle the problem. But the genius of Darwin was such that he not only conceived the idea of natural selection and proved its truth to his own mind, but he so marshaled his facts and principles in linear form in one volume that men were forced to believe. Many of the ideas contained in single sentences or paragraphs of the 'Origin of Species' have been expanded into papers, volumes or treatises by others; and thus made easier to comprehend. The 'Origin of Species' has often been said to be a difficult book to read. So it is, because its ideas are more complex than language can easily convey. Darwin unquestionably saw deeper than he was able to express; and it was the struggle to state what he knew which made the writing of the 'Origin' such an onerous task. But geology as a whole is only less complex than life; and many of us in the smaller matters with which we are attempting to deal have felt the impossibility of conveying more than imperfectly the ideas and relations which are in our minds.

In thinking of the marvelous complexity of the phenomena of geology, and seeking for an analogy which might in some measure express this complexity, it seemed to me that the inhabitants of the globe and their intricate relations furnish an approximate illustration. From each individual or family or hamlet or city or metropolis, there go out on foot, by wheel, by wagon, by railway, by vessel, various products, some of them to the remoter parts of the earth. From each center, by letter, telegram, telephone, communications diverge; if the center be a large one, by thousands of lines. To each center, materials and thoughts in a like manner converge. In a similar way one class of geological phenomena is related to nearly all other classes. They are related as to their material parts, as to the forces and agents acting, and as to principle concerned in their production. For instance, an economic geologist will appreciate that the development of an ore deposit depends upon the nature of adjacent rocks, upon earth movements, upon the resultant deformation, upon fractures, upon vulcanism, upon erosion by water and ice and wind, upon the circulation of underground water. One who hopes to gain even an approximately adequate idea of the genesis of an ore deposit, and an insight as to what is probably beyond the point where the deposit is 'shown up,' must be able to handle the intricate principles of geology. In so far as a geological or mining engineer is a master of these, he rises in his profession; in so far as his knowledge of facts and principles is meager, an ore deposit seems a lawless thing which can be only dealt with on the relatively simple principle of the doctrine of chances. If an ore body happens to be found at any place, follow it. If for some unknown reason it is lost or depreciates in value, prod the ground in all directions, up and down, to the right and left, in the blind hope that chance may find more ore. In many cases nine tenths of this expensive chance work is done in a manner that a fair knowledge of the occurrences, relations and principles of ore deposits would have shown in advance to be wasted.

If the statement thus far be founded on truth, the training of a geologist is a valuable one from an intellectual point of view. It is the fashion for professors in all departments of learning each to hold that a knowledge of his subject is necessary for a liberal education. I have heard each of half a dozen professors, including the classics, history, economics, English, in a single evening each prove to his own satisfac-

tion that a man could not be a good citizen or liberally educated if a knowledge of his special subject were neglected. And at the present time some universities still hold similar views in reference to certain subjects. The claim that this or that subject is essential to a liberal education shows a lack of breadth and lack of capacity to see things in their proper relations. No one language or science is essential to a liberal education. But while this is true, it does not follow that this or that subject may not be essential for a particular career; and in geology capacity to use language for the expression of ideas is absolutely essential. Far be it from my purpose to speak in a derogatory way or to underestimate the value of any line of knowledge. At the present day a man who is trained only in science or only in the humanities has but one hand; that hand may be strong, but the man can never control the affair before him with the power, with the nicety, with which does the man with two hands, one of which is the rich treasures of science, and the other the no less rich and important treasures of the humanities, each doing its part in harmony with the corresponding fullness of results. With a fundamental knowledge of both, the scholar of the future may choose as his chief occupation the clear, cold work of science or that of the humanities, which will always have more numerous followers, because of their direct personal interest.

As I have already intimated, I hold that for the best liberal education one must pursue broadening studies from the first to the last, and also that one must early begin to specialize. If this be true, geology may be said to be a very desirable part of a liberal education; for it is built upon the whole realm of pure science; *i. e.*, the knowledge, which applies not only to the earth and all it holds, including man, but to the universe as well. Because of the breadth of training combined with specialization required of a geologist, it might be shown that geology is one of the most useful studies in giving a person a sense of proportion, ideas as to relative values, of perspective, qualities of the first order in this world. It might be held that the intellectual training of the geologist is of a kind which helps him in dealing with men and things; and, therefore, for handling the world's work. But time does not suffice to develop this part of the subject.

I shall now suppose that a geologist is adequately trained, that he has some power in generalization, and consider what should be his method of work. It is assumed that the young geologist spends a part of each year in the field. This field work should include areal mapping with structural and genetic interpretations. The wider a young geologist has traveled, the more numerous the excursions in which he has taken part, the better will be his equipment. But no general work such as this can supply the place of systematic mapping. And the more exact the mapping is, the better the training. Very frequently the educational value of the mapping in detail of a small area is underestimated. Indeed, I hold that nothing else can take its place. Moreover, the only sure way to test a geologist is to require him to delineate upon a map and in structural sections the detailed phenomena of the field. For my part I have more confidence in the future of a young geologist who has mapped in detail twenty-five square miles, and has got out of the area much that is in it, than that of another who has done no detail work but has run over and written about thousands of square miles. Rarely can the general conclusions of a man who has not done systematic mapping be relied upon. In America there have been conspicuous cases of men calling themselves geologists who have never carefully mapped a square mile. Yet some of these by the un-

discriminating have been regarded as leading geologists. And in one or two cases these men have gained a wide hearing. But the systems which they built up had little or no relation to the world; and they disappeared with the death of their authors. But a geologist must not only do systematic field work at the outset; he must continue to do such work through the years to a ripened age. Not infrequently a geologist, who in early life has done systematic field work, drops this work and continues writing geological philosophy; but this is a precarious course, which sooner or later makes of him what one of our members calls a 'closet geologist.' It is only by never-ending action and reaction between the complex phenomena of geology in the field and reflection as to the meaning of the phenomena that sure results can be obtained.

While one should spend a part of each year in the field, I suspect that many more discoveries of geological principles are made in the office or in the laboratory than in the field. The cow collects the grass in the meadow, and afterwards lies down to chew the cud and digest the food. So the geologist in the field, in the midst of innumerable facts, collects all he can. His notes are a record of his daily collections; and if a successful geologist, of his daily imperfect inferences and deductions. But during the eight or nine months of office and laboratory work he has full opportunity for reflection. He is then likely to see more of the common factors of the facts collected; is more likely to see deeper into the underlying principles which explain them.

This is still more true of the facts collected in the current and during the previous years. Indeed, in the field the observations of the current year are often too prominent on account of their recency, and it is only after some months have elapsed that they take their true proportion in connection with observations of previous years. The use of the material collected not in one year only, but through many years, is *necessarily* done in the office or in the laboratory, and it is only from such large masses of material that broad generalizations can be made.

But the inductions and deductions made in the office and the laboratory during the winter should be tested in the field in the following year in the light of the new ideas. The new ideas should not by a fraction modify the correctness of the observations of the previous years; they should be found as accurate as when made. But observations are always incomplete, and with a new idea one invariably adds valuable observations which were not noted before the idea was available.

I once wrote to a number of the geologists of this and other countries, asking the directions and dips of the dominant cleavages and joints for the various districts and regions of the world with which they were familiar. From only a single geologist did I obtain data of value. Some geologists wrote that they had not time to observe such subordinate phenomena! These men had evidently not learned the principle that the small but numerous agent or force or structure may have as great or greater importance than more conspicuous but less common ones. Darwin should have taught every scientist the principle of the quantitative importance of the small factor when he showed how great is the work of the apparently insignificant earthworm. It seems to me that joints are one of the important phenomena of geology; and this is true whether the point of view be deformation alone, physiography, metamorphism, circulation of groundwater, or the genesis of ores.

While the work of each geologist should be based upon thorough field and office work, and thus have an inductive basis, one should not there stop, but should by deduction ever be looking forward. No one ever

held more firmly to fact as a basis for induction than Darwin; but also, no man has more successfully projected by deduction beyond his facts than Darwin. This in biology was a task of extraordinary difficulty. In geology one who has a firm grasp of the principles of physics and chemistry may be more daring. Their principles, if not more definite than the laws of biology, are at least better known and more simple. Therefore, one, after having observed the facts in a district and grasped the principles which explain them, may deduce what are likely to be the facts in the field and their relations in advance of observation. Or more concretely, after one gets the correct idea as to the meaning of the phenomena for a certain district, he often can tell in advance of observation what he will see; or can find what I call 'geology made to order.'

There is no better or more severe test of a theory than one's capacity to find geology made to order. If observation of the area where the facts are expected to be found in a certain way shows that nature does not obey the order, this is certain evidence that one or more factors in the problem have been omitted and that the theory is inadequate. In so far as the theory is adequate, the geology will be found as anticipated. The reason for this is the very great complexity and delicate adjustment of the phenomena of nature. To illustrate, if the many parts of some complex machine, such as a Hoe press, or a chronometer, were scattered far and wide, and then one should gather some of these parts, and try to fit them, he might find that a certain set fit perfectly. If this were so, he would know to a certainty that these parts are in the correct positions and relations, even if he did not know the relations of these parts to other parts or the purpose of the whole; for so complex and exact is the adjustment that there is but one way to put the parts together. Another set of parts might be found and these made to fit. But doubtless certain parts would not be found. These would be missing links necessary to make a perfect machine. In this situation, if the man had a genius for mechanical construction, and an insight into principles, he might be able to understand the purpose of the whole, and finally to supply the parts which render the whole a useful machine. This he would be able to do just in proportion as he had mechanical insight.

So the geologist fits together his numerous diverse facts. If he finds a solution of his problem which gives accordance to all the numerous facts observed, he may be sure he is on the right track, even if he is incapable of seeing the full truth, for so delicate is the adjustment of facts that where they are numerous there is usually only one way to put them together. Just in proportion as the man has a working knowledge of the principles of physics and chemistry and biology, and the other cognate sciences will he be able to eliminate erroneous explanations, combine the facts into groups under true theories, and correctly infer how the different groups are to be adjusted, how the various facts which seem at first to have no definite relations are related. Or, to put it in another way, in proportion as he knows the rules of the game will he be able to correctly interpret the meaning of phenomena and from them to project into the unknown. The importance of understanding the rules of the game is not often appreciated. To the person who is ignorant of the principles of the various sciences all things are possible. So many wonderful things have happened within the past half century that he thinks it possible for anything to happen. He has no principles by which he can determine whether or not a statement is probably true. Hence all sorts of grotesque notions flourish. Indeed, the very fact that so many wonderful

things have been accomplished makes many more ready to regard as possible almost any absurdity announced by some so-called 'professor.'

Probably at no time in the history of the world has the public shown such ready credulity. Indeed, it seems as if the more grotesque and preposterous an idea the more likely it is to receive attention. And this credulity is not confined to those who are altogether ignorant of science. A man may be a very narrow expert in one direction of science and be wholly ignorant of the rules of the game in reference to another science. For instance, when an eminent biologist says 'bell-ringing, the playing on musical instruments, stone-throwing and various movements of solid bodies, all without human contact or any discoverable physical cause—still occur among us as they have occurred in all ages,'* the statements show the author to be so lacking in a comprehension of the principles of physics that he is unable to estimate whether or not a phenomenon of physics is likely or not likely to be true. It is clear that a man may be an authority as to biology, and yet be so ignorant of the rules of physics that he may be as simple as a child in reference to that subject. Upon the other hand, a man who has a firm understanding of the principles applicable to a case, or, in other words, knows the rules of the game, is likely to be able to reach a rather definite conclusion as to whether or not an explanation which suggested itself is in accordance with those rules, and therefore may be true, or disagrees with some of the well established rules, and therefore is not worth considering.

A geologist once said to me of my teacher and early geological guide, Professor Irving, that he was more correct as to the structure of the Lake Superior region than he ought to have been. But I say that every man is just as correct as to deduction beyond observed facts as he should be. Men with defective basal training and poor intellectual power will always fail when they try to put complex facts together under principles, and especially when they attempt to project by deduction beyond observed facts. But men who have a firm grasp of the principles of the sciences basal to geology, the capacity to correlate these principles and apply them to the facts of geology, will go beyond their observations and by deduction will reach conclusions with perfect confidence which are far in advance of observation. Indeed in this way only can the best geological work be done. After one has projected his deductions in advance of observations, he returns to the field with these new ideas, and then carries his observations farther than he was able to do before. The geologist whose ideas are not continually outrunning his observations will never go far in the science. He whose mind is behind his observations instead of in advance of them, will ever be mediocre. The minds of the leaders of geology are on the mountain heights before their feet have more than touched the foothills.

The conclusions deduced by a scientific genius may go so far in advance of observations that he who announces the conclusions may not be able to make observations which confirm the theories during his lifetime. In such cases subsequent observations made through many years by others will find the phenomena confirming the principles. The truths announced by men of insight are often not accepted by slower men until this later observational work is done. Many cases could be cited illustrating these statements. Darwin, in 1860, *knew* that life had existed that would fill in the great gaps in the very imperfect paleontological record. Since 1860 all the greater gaps have been filled by discovered fossils.

* 'The Wonderful Century,' by Alfred Russell Wallace, p. 211.

Mendeleeff, when he saw the law of the periodic arrangement of the elements, *knew* that elements exist which would fill the gaps; but it took many years of work by many men to find a part of them; and during the past few years a half dozen or more of the vacant places have been occupied. Each geologist, each scientist, now as in the past, is just as right as he should be. The scientific seers will ever go far in advance and guide others, even as did the spiritual seers of old.

The scope of these observations doubtless extends beyond geology. Much of what has been said is true of knowledge as a whole, not restricted to one subject. But I shall have accomplished my purpose if what I have said be true of geology; for if my conclusions be well founded, they furnish the basis upon which courses leading to degrees in professional geology should be laid out, and to methods of good geological work in the field and in the office.

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## *SECTION D, MECHANICAL SCIENCE AND ENGINEERING.*

Papers were presented as follows:

*The Trend of Progress of the Prime Movers:* Professor R. H. Thurston, Cornell University.

1. The great prime movers have been known in type and in some cases, in specific forms, still familiar, since the days of Hero of Alexandria and probably may have been in some forms known to prehistoric Greeks and Asiatics. The sources of power—heat, falling waters, the winds—all were well known when the earliest scientific writings were produced, and the famous Alexandrian 'Museum' contained illustrations and examples of even some of our simpler familiar types of steam-engine and steam-boiler.

2. The prime movers made little progress toward their present perfection until the commencement of the eighteenth century, when the steam-engine of Savery and Worcester, the old steam fountain of Hero the Younger, was displaced by the modern steam-engine, a real train of mechanism, devised by Newcomer, the inventor of the modern type of machine, about 1707. Meantime, water-wheels and windmills were taking form and the prime movers thus were preparing to do their part in the world. Improved by Watt, the steam-engine assumed the largest part of the load, but the water-wheels and windmills have always done a large amount of work in the aggregate. The industrial world came after a time to be moved as a whole by the prime mover of Watt, and steam power has of late performed vastly more work than could the whole population of the world, unaided.

3. The gas-engine has a history of about the same length as the steam-engine in its form of a prime mover for mills. It was introduced about a century ago and has progressed meantime less rapidly than its rival, but since the middle of the nineteenth century its advance has been steady, both in construction and in employment. To-day this motor has assumed a perfection of design and construction and has attained an excellence of economical performance which is rapidly bringing it into use in a great variety of fields and is, in fact, making it a promising competitor with the older motor.

4. The other motors have been meantime greatly improved. The modern hydraulic turbine has attained an efficiency of eighty per cent. and upward and the contemporary windmill is a scientifically designed, skillfully made apparatus of but little if any less perfection, for its purpose, or efficiency in utilizing its form of energy. All the common forms of prime movers have now, thanks to advances in sciences related to